17th U.S. National Congress on Computational Mechanics, July 23 - 27, 2023, Albuquerque, New Mexico, USA

Title: Degradation of carbon fiber microstructures due to oxidative etch pitting.

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In order to understand the influence of etch pits on the material properties of carbon fiber microstructures, we use the Porous Microstructure Analysis (PuMA) [1,2] software to create realistic pitted structures from virgin fiber structures and then analyze their degradation as the degree of pitting increases. For that purpose, we developed a pitting module within PuMA that creates pits with user-defined geometry (shape, size) and distribution (defect density) on the surface of arbitrary microstructures. In this work, we consider FiberForm microstructures, which are commonly used as the base material for ablative thermal protection systems (TPS). Using the new pitting module, we mimic the evolution of etch pits on FiberForm as it occurs from oxidation in ablative heating environments, by first importing the virgin FiberForm structure from a micrograph scan and then imposing different pitting conditions by varying pit radii and defect densities. We then leverage PuMA's capabilities to calculate material properties for each structure. The results clearly show the degradation of thermal conductivity and structural integrity as etch pits grow, and furthermore highlight the complex evolution of the surface topology, which results in significant changes of the flow-geometry and chemical gas-surface interactions. Furthermore, a comparison of these changes with the case of shrinking fibers, which has heretofore been the standard for modelling ablation of carbon structures, yields significant differences. For example, we observe the formation of small chunks of fibers as pits grow in size, which could be released into the surrounding flow environment as spallation particles. This motivates us to continue our efforts of modelling pitting as an integral part of the structural degradation of carbon fiber structures in oxidation environments, which will ultimately improve our understanding of failure mechanisms in those materials.

[1] J. C. Ferguson et al., "PuMA: the Porous Microstructure Analysis software", SoftwareX 7 (2018): 81-87.
[2] J. C. Ferguson et al., "Update 3.0 to "PuMA: the Porous Microstructure Analysis software"", SoftwareX 15 (2021): 100775.